LWA Memo No. 151

LWA Signal Delays and Time Tagging

Larry R. D'Addario
Jet Propulsion Laboratory, California Institute of Technology[1]

2008 December 22, 2008

For a beam-forming channel of an LWA station, consider a plane wavefront arriving from the direction of the beam. We can imagine that the sky contains only a point source in that direction. Let t_0 be the wavefront's time of arrival at the station's reference position (an arbitrarily chosen place, but probably near the center of the station's antennas for convenience). The same wavefront induces a signal in each of the antenna stands, and those signals propagate through the telescope system. Ultimately they are combined, and we end up with one polarization pair of output signals for that beam. (From now on in this memo, we ignore the fact that there is a pair of signals and consider just one of them.)

Each antenna's signal suffers various time delays before and after combining until it finally arrives at the output. The total delay can be represented as

$$T = G_i + C_i + g_i + c_i + x + L + F(B) \qquad (1)$$

where G_i is the geometrical delay in propagation from the reference position to antenna i (possibly negative); C_i is the delay from antenna i to the corresponding digitizer (which I will call the cable delay, even though it also includes propagation through the front end and analog receiver electronics); g_i and c_i are compensating delays inserted in the digital electronics, nominally equal to $-G_i$ and $-C_i$, respectively; $x > 0$ is a fixed extra delay inserted in the digital electronics in order to keep $x + c_i + g_i$ positive for all antennas and all possible beam directions; L is the extra signal latency caused by pipelining of the digital processing; and $F(B)$ is the delay through the final filter (after combining), which is a function of the selected filter bandwidth B. Here we have neglected the fact that some of the delays vary with frequency across the bandwidth due to the frequency responses of the components, on the assumption that care was taken to minimize such effects[2].

The sum of the first four terms in (1) is nominally zero for all antennas, and this is the mechanism by which the array is made to have high gain in the desired beam direction. Sometimes it may deliberately be made non-zero for some antennas in order to accomplish beam shaping, but we regard these as intentional departures from nominal. Delay x is implemented separately for each antenna's signal (along with g_i and c_i), but its value is made exactly the same for all. Delay L is distributed through the processing path of each signal, and it would naturally be different for each antenna because the individual signals are added to the sum at different places along a chain, but the design has carefully included a compensating delay in each antenna's path in such a way that the net delay at

---

[1] Government sponsorship acknowledged.

[2] Dispersion in the antenna and cable, if not well matched among the antennas, may be partly cancelled in the digital filter that forms part of g_i. Dispersion common to all antennas may be partly cancelled in the final filter. Otherwise, digital filters will be designed to have linear phase and hence be dispersionless. In general there will be some residual dispersion, so that the compensating delays g_i and c_i are accurate only at one or a few frequencies in the processed bandwidth.

the final summing point is the same for all. The final filter with delay $F(B)$ is applied only to the combined signal, so it is naturally the same for all antennas.

All of the delays implemented in the DP subsystem are known to it, and therefore can be taken into account. In particular, the nominal delay $T_{\text{nom}} = x + L + F(B)$ is known. This does not mean that T_{nom} is always the same for the same selected bandwidth because the latency L depends partly on FIFO buffers whose state is not directly under control of the designers. Thus L could change across a power cycle, system reset, or major re-configuration. It will nevertheless be measured within the hardware so that its value during any observation is known[3].

Based on the above discussion, we propose to consider the time of a signal sample that arrives at the output of the final filter when the station clock time is t_1 to be

$$t_{\text{tag}} = t_1 - T_{\text{nom}} ,$$

since this is our best estimate of t_0, the time of arrival of the corresponding wavefront at the reference position. To the extent that the DP subsystem provides a "time tag" for any sample, this is the value that it should use. Alternatively, if the timing of samples is the responsibility of the Data Aggregation and Communication Subsystem, DP can provide it with the current value of T_{nom} via the Monitor/Control Subsystem. In this way, the peculiar latency L of the DP subsystem, along with its somewhat arbitrary value of x, need not be taken into account by later processors, nor need they account for variations of delay with bandwidth B. This is especially important when combining the station signals at a correlator because it is possible that one or more components of T_{nom} will not be the same for all stations. There will still be a peculiar delay for each station due to differences between T and T_{nom} (for example, the cable delays C_i may not all be absolutely compensated, even if their *differences* within the station have been accurately removed by c_i), and this will need to be calibrated astronomically. If residual dispersion in the station beam signals is significant and varies among stations, the calibration may need to be a function of frequency.

Various copies of the station clock may exist in different hardware modules and in computers. All should be synchronized (but perhaps to varying accuracies) via distributed reference signals and messages. The module responsible for labeling the times of output samples must contain a particularly accurate copy of the station clock, and to that extent it might be considered the "master" copy. The DP2 module should contain a counter driven by the 196 MHz sampling signal, and this counter's value can serve as a station clock with resolution 5 nsec and ambiguity interval determined by the counter's length (where 44 bits is sufficient for 24 hours).

---

[3] There are several ways to do this, including intermittent direct measurement and the use of periodic time markers in the signals. The exact implementation has not yet been decided.